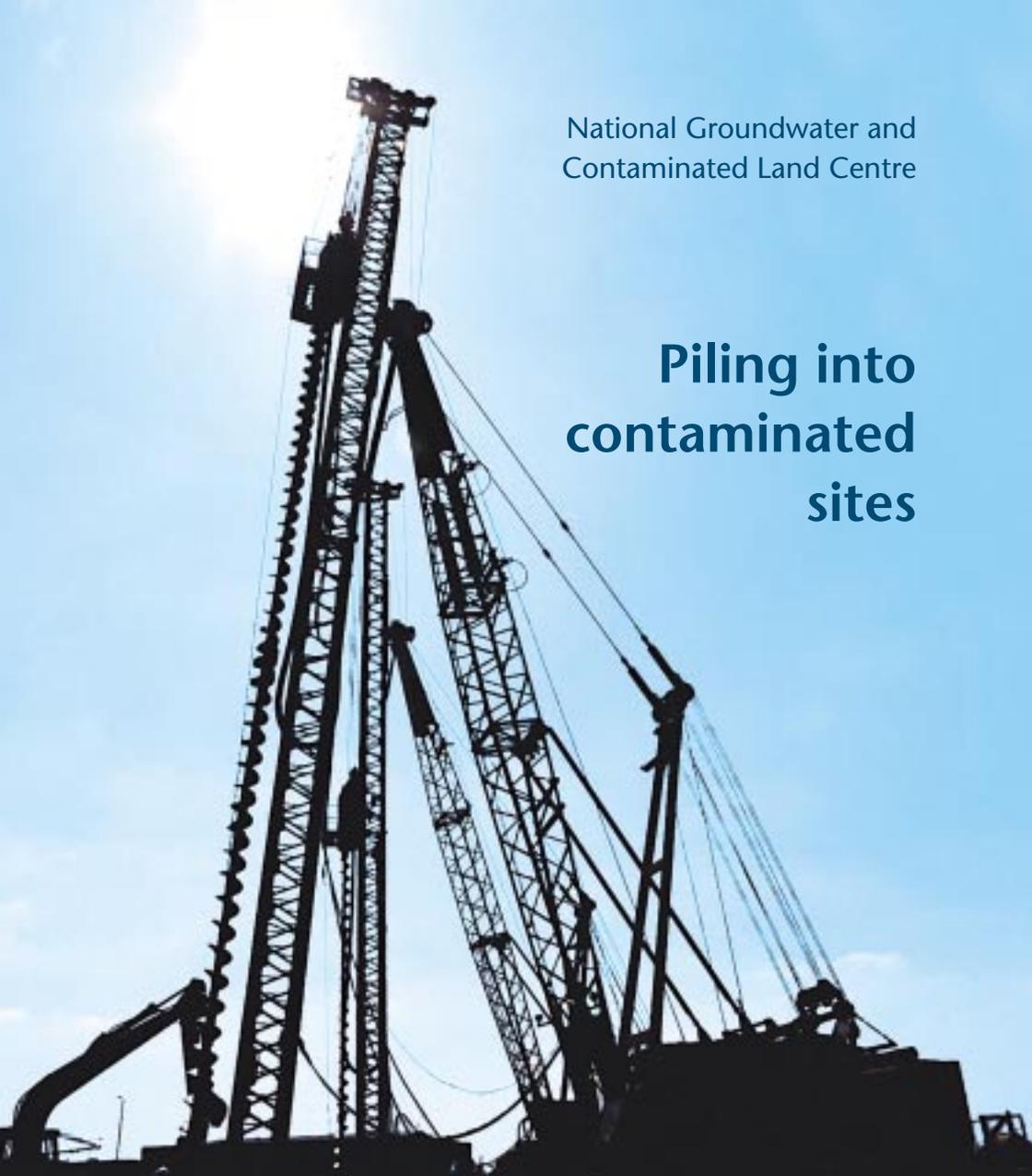


National Groundwater and
Contaminated Land Centre

Piling into contaminated sites



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Piling and penetrative ground improvement methods on land affected by contamination: Summary guidance on pollution prevention.

Scope

This booklet summarises recent guidance¹ produced by the Environment Agency (the Agency), and gives a brief introduction to potential environmental hazards associated with piling through contaminated soils, and how sites may be improved. It focuses on the effects of piling on any controlled waters, especially groundwater, with brief consideration of gas and human health issues. It is not intended to provide comprehensive information on all methods and site conditions but it is based on current good practice.

1. Introduction

Piles are columnar elements in foundations, which transfer loads from structures through weak or compressible strata, down to stronger material capable of supporting the loads. Penetrative ground improvement techniques enhance the bearing capacity of loose and compressible soils, rendering them suitable for shallow foundations.

Piling and penetrative ground improvement methods are commonly used on “brownfield sites”, where previous development has resulted in a thickness of loose or compressible soils and “made” ground, which may be contaminated. These methods typically penetrate to greater depths than standard foundations. Consequently, they are likely to increase the risk of contamination being transported by creating new pathways.

¹ Environment Agency (2001) *Piling and Penetrative Ground Improvement Methods on Land Affected by Contamination: Guidance on Pollution Prevention*. NC/99/73

The Agency recommends that piling on contaminated sites underlain by aquifers is avoided where possible, and that non-invasive methods, such as rafts, should be used instead. Where there is no alternative to piling, a method should be selected that minimises the risks of groundwater pollution or gas migration. Mitigation measures and/or environmental monitoring may need to be incorporated into the design. In such circumstances the method selected should be presented in a “Foundation Works Risk Assessment Report” which should summarise:

- the process of the assessment, including the pollution scenarios that may occur using these techniques;
- the potential mitigation measures that may be appropriate;
- proposals for any monitoring;
- particular problems and uncertainties associated with the methods chosen.

2. Legislation and regulatory context

Redevelopment of land is generally controlled through the Town and Country Planning system. The Agency, as a statutory consultee, provides comments to the planning authority on planning applications involving contaminated land. The planning authority is responsible for enforcing any conditions concerning water protection included in its decision notice or other controls; for example requiring a Foundation Works Risk Assessment Report to be approved before any works are undertaken.

The Agency prefers to see the potential for pollution prevented through measures introduced via the planning process, but there may be instances where pollution of controlled waters is occurring or may occur. The Agency has a number of powers under the Water Resources Act 1991 (WRA91). It is an offence under section 85 of WRA91 to “...cause or knowingly permit any poisonous, noxious or

polluting matter...to enter any controlled waters”, which includes groundwater. Section 161 A-D of WRA91 and the Anti-Pollution Works Regulations 1999 give the Agency powers to remedy or forestall pollution and serve “works notices” requiring measures to protect or remediate controlled waters.

Part IIA of the Environmental Protection Act (EPA) 1990 provides a regime for the identification and remediation of contaminated land. It sets out a framework for apportionment of liabilities for remediation of contaminated sites, which is based on the “polluter pays” principle. Any person who causes or knowingly permits contaminating substances to be in or under the land may be required to undertake remediation and meet the costs; they may also face prosecution.

If waste (e.g. contaminated arisings from the piling works) is generated, there is a Duty of Care under Part II of EPA 1990 on those responsible for the waste, to ensure that it is managed and transported properly, and disposed of safely to an appropriately licensed waste management facility.

3. Piling and penetrative ground improvement techniques

Piling and penetrative ground improvement techniques have been split into three classes, based on the installation method or the effect of the installation on the soil mass. Piles can be further subdivided according to the construction and installation methods used (see **Table 1**).

Displacement piling

Displacement piling methods, also known as driven piling, form the pile by displacing soil horizontally from the space to be occupied by the pile, without the removal of soil to the ground surface. The density of the soil around the pile is increased and its permeability is reduced. Small displacement piles comprise steel sheet, H or I (in cross section), hollow tube sections, or hybrids such as the auger pile. Large displacement piles include pre-cast concrete elements, closed-end steel tube/timber sections,

or may be cast *in situ* inside a casing or in a pre-formed void.

Non-displacement piling

Non-displacement piling techniques, often called “bored” piling, extract a core of soil and replace it with the pile, which is typically formed by casting concrete *in situ*. Displacement of the surrounding soil is minimised. Temporary support of the hole prior to placing the pile is often required.

General characteristics of penetrative ground improvement

Penetrative ground improvement methods involve penetration of the full thickness of the soil being improved, up to a maximum depth of about 5 metres. A combination of densification and the introduction of granular material to form stone columns may improve the physical (geotechnical) properties of the ground. Vibro concrete columns are formed when concrete rather than granular material is introduced to the hole.

Table 1. Piling and penetrative ground improvement methods considered in Report NC/99/73.

Generic method	Specific methods considered
Displacement piles	Pre-formed solid pile Pre-formed hollow pile Displacement cast-in-place pile
Non-displacement (replacement) piles	Non-displacement cast-in-place pile Partially pre-formed pile Grout or concrete intruded pile
Penetrative ground improvement methods	Vibro replacement stone column improvement methods Vibro concrete column (VCC)

Note: Refer to the guidance document¹ for detailed information on the different piling and penetrative ground improvement techniques and their environmental impacts.

4. Hazard identification: potential adverse environmental impacts

The Source–Pathway–Receptor (S-P-R) linkages associated with piling and ground improvement works must be considered in a site-specific context.

The presence of environmental receptors that could be harmed by contaminants mobilised by ground works are defined by the hydrogeological properties of the

underlying strata, the proximity to other receptors such as surface water bodies, the history, use and occupation of the site and its surroundings.

In the case of piling and ground improvement works, concerns about water protection are likely to be most acute when:

- contaminants are present on the site and ground works could allow them to migrate;

- piling would breach an aquitard or connect two previously discrete aquifers;
- the site overlies a Major or Minor Aquifer;
- the site is located within a Source Protection Zone (SPZ);
- groundwater is currently of good quality;
- the water table is shallow or likely to be intersected by piles;
- the geological strata are fractured or fissured;
- works are close to a surface water body and run-off from arisings could pollute those waters.

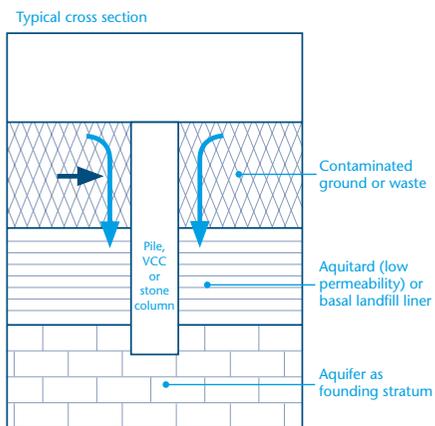
The Agency's response to proposals for piling on contaminated sites will be based on the overall level of risk that piling presents, the techniques, mitigation measures and the quality assurance and control (QA/QC) methods proposed. In sensitive situations, the Agency may require a risk assessment to be undertaken and mitigation measures (including groundwater monitoring) to be incorporated. In the most sensitive situations, the Agency will object to proposals that present an unacceptable pollution risk.

The Agency has identified six potential pollution scenarios that are of particular concern. These are described in **Table 2** together with the S-P-R linkages for each scenario.

Table 2. Pollution scenarios and summary of the Source–Pathway–Receptor linkages

Pollution Scenario 1

Creation of preferential pathways through an aquitard to allow potential contamination of an aquifer



Source –

contaminated made ground, waste or contaminated perched groundwater

Pathway –

pile/stone column, pile/soil interface or disturbed ground around pile

Receptor –

groundwater in aquifer; typically in solid strata in which pile is founded

Examples –

1) contaminated ground above clay deposits, which sit on permeable solid strata such as the Chalk. Disturbance of aquitard layer could create a migration pathway for contaminated perched water in the made ground

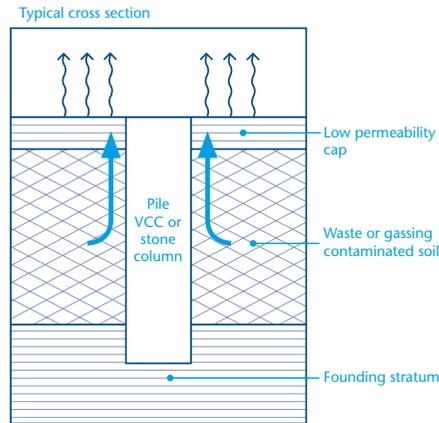
2) similar to 1) above: a closed landfill with a basal liner, to be redeveloped, with structural loads supported on piles founded in permeable solid strata below the basal liner

Issues to consider

- **Polluting substances** – leachable/mobile form?
- **Groundwater** – directly beneath the site/in strata penetrated by piles/Major or Minor Aquifer/in hydraulic continuity with a surface water body?
- **Aquitard/Aquifer** – Will the piling or ground improvement method breach aquitard/the basal liner of a landfill site/penetrate an aquifer?
- **Migration** – Could contaminants in near surface deposits migrate into underlying aquifer or surface water body?
- **Pile material** – Is the pile made out of a material that could allow passage of contaminants?
- **Preferential flowpath** – Will the piling or ground improvement method create a flow path for migration of contaminated perched water/leachate into an aquifer/surface water body?

Pollution Scenario 2

Creation of preferential pathways through a low permeability surface layer, allowing migration of landfill gas, soil gas or contaminant vapours to the surface



Source –

gassing landfilled waste or contaminated ground

Pathway –

pile/stone column, pile/soil interface or disturbed ground around pile

Receptor –

users of built development/structures

Examples –

1) development on old landfill, or “brownfield” site when ground levels have been raised using gas-generating fill. Disturbance of an impermeable capping layer installed to manage the existing gassing regime may create migration pathways for landfill gas, air-flow pathways rendering a gas extraction system ineffective or increase the rate of degradation and volume of gas generated

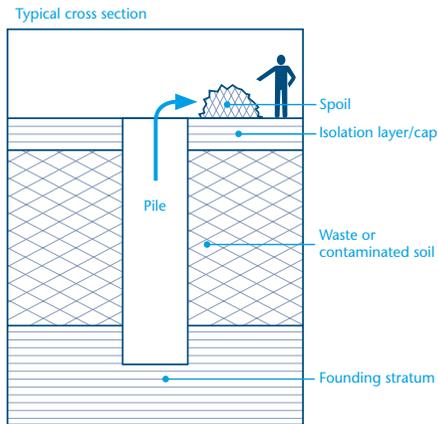
2) similar to 1) above: where land has been contaminated with volatile compounds, such as petroleum spirit

Issues to consider

- **Polluting substances/gas** – Is the contamination present a potential source of landfill gas or vapours?
- **Preferential flowpath** – Will the piling or ground improvement method create a flow path for the migration of gas/vapour to surface?
- **Gas risk** – Is there a risk from accumulation of gas/vapours in enclosed spaces in the proposed development? Will they be mitigated by using standard gas protection measures?
- **Air quality** – Are gas releases to atmosphere acceptable?

Pollution Scenario 3

Direct contact of site workers and others with contaminated soil arisings that have been brought to the surface



Source –
contaminated soil or waste

Pathway –
direct contact with excavated arisings, run-off to surface waters

Receptor –
human receptors (construction workers, site users, etc) and surface water

Examples –
1) piling creates arisings which contain contamination that could come into contact with sensitive receptors. The piling process is likely to mix contaminated and uncontaminated soils, producing an increased volume of contaminated materials for disposal. Contaminated piling arisings may also cause cross-contamination to isolated layers

Issues to consider

- **Contamination hazard** – Are contaminants present in the soil/groundwater at sufficient concentrations to pose a hazard to human health or the environment?
- **Arisings** – Could the piling or ground improvement method bring potentially contaminated soil arisings to the surface?
- **Disposal** – Are measures in place to contain/dispose of arisings in a safe manner?

Pollution Scenario 4

Direct contact of the piles or engineered structures with contaminated soil or leachate causing degradation of materials

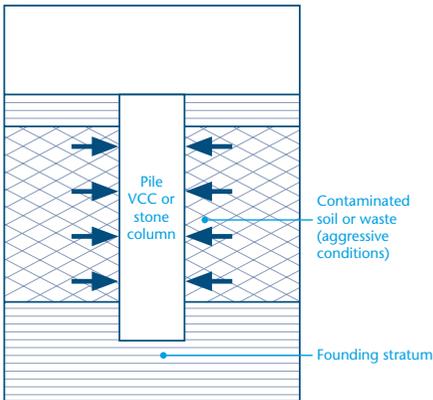
Source –
contaminated soil, waste or leachate

Pathway –
direct contact with pile

Receptor –
built development (and users)

Examples –
1) some contaminants in soil/leachate may be aggressive to pile materials causing degradation of piles, reducing or eliminating their load carrying capacity, and possibly creating further migration pathways

Typical cross section

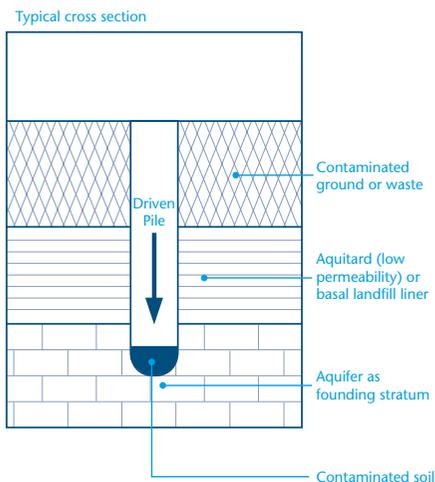


Issues to consider

- **Degradation** – Do the soils or their leachability present a risk to the performance or durability of the pile material?

Pollution Scenario 5

The pushing of solid contaminants down into an aquifer during pile driving



Source –
contaminated soil

Pathway –
driving down of soil in contact with the sides/butt end of pile, or “plugging” of open-ended pile

Receptor –
groundwater in aquifer, typically in solid strata in which pile is founded

Examples –

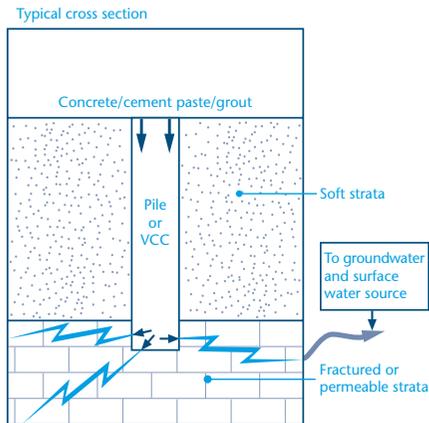
- 1) soil in contact with the sides of a driven pile and material below the butt end of a solid or closed-end pile dragged down
- 2) open-ended tubular piles become “plugged” with soil, enabling material captured near the surface to be transported downwards within the tube towards the founding level

Issues to consider

- **Polluting substances** – leachable/mobile form?
- **Groundwater** – directly beneath the site/in strata penetrated by piles/Major or Minor Aquifer/in hydraulic continuity with a surface water body?
- **Aquitard/Aquifer** – Will the piling or ground improvement method breach aquitard/the basal liner of a landfill site/penetrate an aquifer?
- **Drag down** – Does the piling method involve the use of blunt-ended solid or closed-end piles that could drag down soil or open-ended tubular piles that could become “plugged” with soil?

Pollution Scenario 6

Contamination of groundwater and, subsequently, surface waters by wet concrete, cement paste or grout



Source –

concrete, cement paste or grout introduced to the ground

Pathway –

flow within highly permeable or fractured strata

Receptor –

groundwater and surface water

Examples –

1) loss of wet concrete, cement paste or grout in fast-flowing groundwater, associated with fractured/jointed rocks e.g. limestones, Chalk or permeable gravel formations. If retardant additives are used pile materials could take several hours to set.

Issues to consider

- **Contamination** – Does the method involve introducing wet concrete, cement paste or grout into the ground?
- **Groundwater** – directly beneath the site/in strata penetrated by piles/Major or Minor Aquifer/in hydraulic continuity with a surface water body?
- **Aquifer** – Highly fissured or granular strata? Is the groundwater in the aquifer fast-flowing?

Note: Other scenarios may be identified in particular circumstances.

5. Hazard assessment

The potential for piling techniques to cause pollution should be considered and the likely environmental consequences estimated. This will require an understanding of site-specific conditions (e.g. hydrogeology, contaminant properties, piling placement methods) and through risk assessment will allow estimation of the scale of potential problems and direct design of any mitigation measures.

It is often helpful to develop a ‘conceptual model’ of the site, and how the ground works could affect the environment.

6. Recommended risk assessment framework

The risk assessment framework proposes a decision-making process that indicates where piling is unacceptable or allows selection of appropriate piling methods and mitigation measures (see guidance document¹ for further details). The

recommended risk assessment process is given in **Figure 1**. It provides a framework for risk assessment method selection and appropriate QA/QC measures. This can be presented in a “Foundation Works Risk Assessment Report” (see **Table 3** for suggested contents).

The removal of potentially adverse impacts will normally be achieved through specific mitigation measures (e.g. changes to the installation method). A number of issues to be considered are:

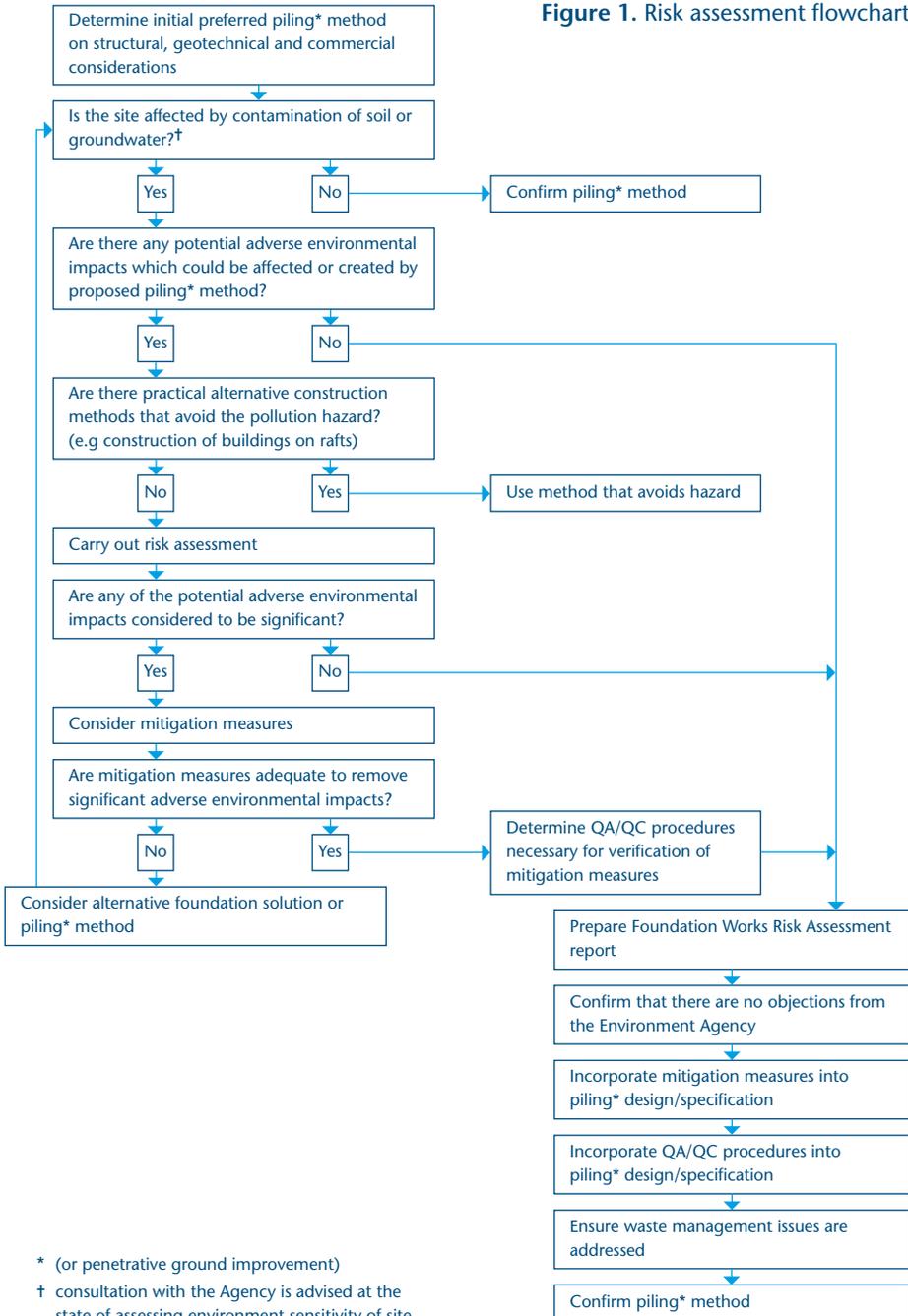
- do the mitigation measures themselves have any adverse environmental impacts?
- are the mitigation measures adequate to remove significant adverse environmental impacts?
- how will the mitigation measures be specified to ensure that they are incorporated and verified during the installation works?
- what monitoring requirements are there?

- who will verify the inclusion and adequacy of the mitigation measures?
- could subsequent building works adversely affect the mitigation measures and how will this be prevented?

Table 3. Suggested contents of Foundation Works Risk Assessment Report

-
1. Introduction: describing the site setting including geology, hydrogeology, soil or groundwater contamination, topography, geotechnical considerations and requirements for piling or ground improvement methods.
 2. Initial selection of piling method: Justification of the preferred method.
 3. Identification of potential adverse environmental impacts.
 4. Site-specific assessment of the identified risks to the environment, workers and end users.
 5. Identification of any changes to preferred method. Consideration of mitigation measures that may be required.
 6. Identification of QA/QC methods and measures.
 7. Justification of selected methodology: including mitigation, QA/QC and monitoring measures, with regard to geotechnical, financial and environmental considerations.
-

Figure 1. Risk assessment flowchart



* (or penetrative ground improvement)

† consultation with the Agency is advised at the state of assessing environment sensitivity of site.

Useful further reading

Environment Agency (1996) Pollution Prevention Manual. Internal guidance document.

Environment Agency (1998) *Policy & Practice for the Protection of Groundwater*.

The Stationery Office.

Environment Agency (1999) *Methodology for the derivation of remedial targets for soil and groundwater to protect water resources*.

R&D Publication 20.

Environment Agency (2000a) *Risks of contaminated land to buildings, building materials and services: A literature review*.

R&D Technical Report P331.

Environment Agency (2000b) *Introducing Environmental Risk Assessment*.

National Centre for Risk Analysis and Options Appraisal.

Environment Agency (2000c) *Guidance for the safe development of housing on land affected by contamination*.

R&D Publication 66. The Stationery Office.

Environment Agency (2001) *Piling and Penetrative Ground Improvement Methods on Land Affected by Contamination: Guidance on Pollution Prevention*.

National Groundwater & Contaminated Land Centre, Project NC/99/73. Solihull.

More information

The National Groundwater and Contaminated Land Centre's Vision is: **an improved groundwater and land environment for present and future generations**.

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